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Influence of Mesquite Biochar on the Geotechnical Properties of Highly Plastic Clay

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ABSTRACT

Biochar is a solid byproduct produced during the pyrolysis or gasification of waste biomass in the absence of oxygen. Due to its richer physicochemical features, it has recently received interest in a variety of agricultural and environmental applications. The high pH, CEC, specific surface area, and surface functional groups of biochar are all dependent on the feedstock type and production method. However, the use of biochar in geotechnical engineering for bioengineered structures is limited. In the present study, the influence of biochar produced from mesquite hardwood under slow pyrolysis conditions on the physical and mechanical properties of high-plasticity clay was determined. In a series of laboratory tests, the variation in Atterberg limit, specific gravity, pH, compaction properties, and free swell index of CH soil treated with 5% and 10% biochar was investigated. On the compacted biochar soil mixes, unconfined compressive strength values were also measured. The results obtained showed an increment in the Atterberg limits, pH, as well as OMC values, whereas there was a decrement in the specific gravity and MDD values with the addition of mesquite biochar. The UCS values showed a marginal increment due to the addition of biochar to the soil. According to the study's findings, biochar is an effective and environmentally friendly alternative for use as a construction material.

Keywords: Pyrolysis, Hardwood biochar, Unconfined compressive strength

1 INTRODUCTION

Biochar is a novel renewable material synthesized from various types of biomass like plant species, agroforestry waste, animal manure, and industrial wastes (Subratti et al., 2021). It is formed in the absence of oxygen by a thermochemical degradation process. Its distinctive properties, including high aromaticity, pH, CEC, specific surface area, and surface functional groups, have sparked interest in biochar's potential use in a number of agricultural and environmental applications (Sahoo et al., 2021). The composition and physicochemical properties of biochar are highly dependent on the feedstock type and the method of its production. Usually, pyrolysis is the preferred method for its production.

Biochar has been proven a promising alternative material in different areas due to its rich inherent characteristics. (Liu et al., 2021) investigated the use of cow manure biochar for the sorption of a typical wastewater pollutant. (Cobbina et al., 2019) produced biochar from groundnut shells at 350^0 C and 700^0 C to explore its use as an absorbent for the removal of heavy metals like lead, cadmium, and mercury from an aqueous solution. Apart from this, biochar has also been used in soil for the removal of various organic and inorganic pollutants. Biochar also appears to improve crop productivity in coarse-textured soils by increasing soil fertility and reducing nutrient loss. (K. R. Reddy et al., 2011) has suggested the use of wood-based biochar for the reduction of greenhouse gases like CO_2 and methane in landfill soil. Seeing the potential of biochar, it has also been utilized as an insulating material for construction purposes and improving the early strength of cement mortar and concrete (Gupta et al., 2018, 2021). (Gupta & Kua, 2019) had explored the effect of biochar particle size on strength development and permeability of cement mortar and found that finer particles of biochar have better performance than normal biochar for early strength improvement. (Akhtar & Sarmah, 2018) replaced cement up to 1% of the total volume with biochar to investigate its effect on the mechanical properties of concrete.

On the contrary, the use of biochar in geoengineering infrastructure is still rare. (K. R. Reddy et al., 2015) assessed the engineering properties of biochar-amended soil for use in landfill cover and in-ground filtration systems. They found that the amendment of biochar to soil decreases the maximum constrained moduli values of soil with increasing percentages of biochar amendment along with an increase in the shear strength of composites.(Bordoloi et al., 2020) found that the addition of plant and animal-based biochar increased the Atterberg limit and alkalinity of the soil. But a decrement in shear strength of biochar amended soil by 25-50% was observed. (Hussain et al., 2021) experimented with the effect of mesquite biochar on the hydraulic properties of silty sand and pure sand for potential application in bioengineered structures. Considering the limitations of previous research works, it is found that more research is required to understand the effect of biochar on the geotechnical behavior of different soils.

Therefore, the aim of the current research is to investigate the influence of biochar produced from hardwood under slow pyrolysis conditions on the physical and mechanical properties of stabilized high plasticity clay. The main objectives are: (1) to determine the Atterberg limits, specific gravity, and soil pH of virgin soil and biochar-amended soil, (2) to assess the swelling potential of soil with 5% and 10% biochar doses, and (3) to determine the mechanical characteristics of soil such as maximum dry density (MDD), optimum moisture content (OMC) and unconfined compressive strength. This study may help to understand the potential use of biochar as an effective and environmentally friendly construction material as well as a binder in the stabilization of expansive soils.

2 MATERIALS AND METHODOLOGY

Virgin soil used in this study was collected from a nearby area in Surat city, Gujarat, India. The basic geotechnical properties were determined using the IS 2720 code procedures, and it was classified as highly plastic clay (CH) according to the unified soil classification system. Biochar used in this study was procured commercially from greenfield eco solutions, Jodhpur, Rajasthan, India. It was made from Mesquite hardwood, which was slowly pyrolyzed at 500^0 C. It was powdered, sieved to a 2mm mesh size, and stored in an airtight container for later use. Table 1 shows the properties of mesquite biochar. The Scanning electron microscopy (SEM) analysis of biochar shown in figure 1 displays the number of micro and macro pores present in it (Hussain et al., 2020).

Table 1. *Properties of Mesquite biochar*

Property	Value
Pyrolysis temperature	500^o C
pH (1:5)	8.5
CEC	11 meq/100 g
Organic Carbon	>70%
Ash content	<2 %
Moisture content	<2%
Specific gravity	<1
Bulk density	160-260 kg/m^3

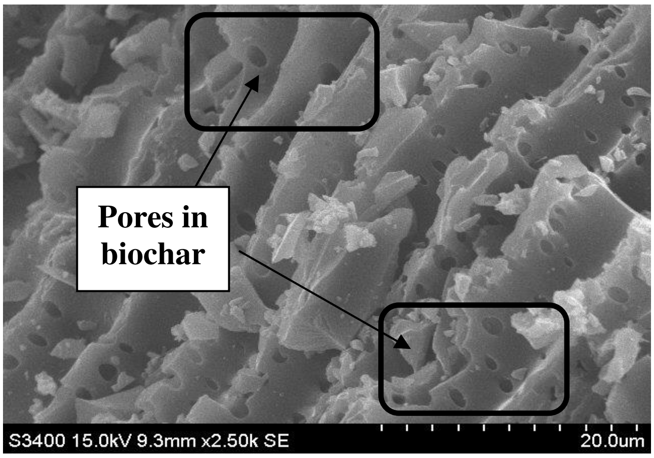

***Figure 1**. SEM image of mesquite hardwood biochar*

Mesquite biochar was added to the soil at a rate of 5% and 10% based on the weight of the dry soil. Following that, the physical and index properties of the soil biochar composite, such as liquid limit, plastic limit, specific gravity, and free swell index, were determined according to the IS standard (IS 2720-5(1985), (IS 2720-3(1980), IS 2720-40(1977)). The pH of the soil biochar composite was tested using a 1:2 soil-to-water ratio (V. A. Reddy et al., 2019). To determine the MDD and OMC of the mixes, a light compaction test was performed as per IS 2720-6 (1980). After that, cylindrical specimens with a diameter of 50 mm and a height of 100 mm were created in order to perform an unconfined compressive strength test on them (IS 2720-10(1991)). All tests were carried out on triplicate specimens, and the average value of the parameters was considered in this study.

3 RESULT AND DISCUSSION

3.1 Effect of biochar on physicochemical properties of expansive soil

Table 2 provides the values of Atterberg limits, specific gravity, and pH of the virgin soil and biochar-amended soil. It is observed that the liquid limit and plastic limit of soil biochar composite are more than that of virgin soil. The main reason for such an increment is due to the high porosity and water absorption capacity of biochar (Sadasivam & Reddy, 2015). The presence of intra pores in biochar increases the specific surface area of biochar-amended soil, resulting in higher Atterberg limits. Along with this, it was noted that the plasticity index of soil decreases with the addition of biochar at 5% and 10% proportion. These results are consistent with the studies conducted in the past by (GuhaRay et al., 2019) and (Sarkar et al., 2020).

The specific gravity of virgin soil was found to be as low as 2.21 due to the presence of some organic matter. This value was reduced with the addition of biochar at 5% and 10% in the soil to 1.82 and 1.55, respectively. This is attributed to the addition of lighter biochar particles to the soil, which changes the overall soil matrix (K. R. Reddy et al., 2015). The swelling potential of bare soil was as high as 54% due to the presence of montmorillonite minerals in expansive soils. The incorporation of hardwood biochar at a 5% dose contributed to reducing the free swell index to 47%, which showed a further reduction to 38% at a 10% biochar dose.

The pH of virgin soil was measured to be 7.85 using a pH meter. With the addition of biochar at 5% and 10% proportion, the pH of the soil increased significantly to 8.17 and 8.26. The alkaline nature of biochar, which is the result of its production at a high temperature of 500^0 C, accounts for the high pH of the soil biochar composite (Wani et al., 2022).

Table 2. *Physico- chemical properties of biochar amended soil*

Property	Virgin soil	Soil+5% Biochar	Soil+10% Biochar
	Atterberg Limit		
Liquid Limit (%)	68.2	70.1	72.4
Plastic Limit(%)	37.4	40.3	44.3
Plasticity Index	30.8	29.8	28.1
	Specific Gravity		
	2.21	1.82	1.55
	Free swell Index (%)		
	54	47	38
	pH		
	7.85	8.17	8.26
	Compaction characteristics		
MDD (g/cc)	1.7	1.44	1.38
OMC (%)	23.7	28.5	30.5

3.2 Effect of biochar on compaction characteristics

The compaction curve for the soil with 0%, 5%, and 10% addition of mesquite biochar is shown in figure 2. The MDD and OMC of virgin soil, respectively, were 1.7 g/cc and 23.7%. The MDD value decreased and the OMC value increased when biochar was added to the soil. For example, soil MDD was 1.44 g/cc and OMC was 28.5% with a 5% biochar amendment. The same pattern was seen with the 10% addition of biochar in the soil. The reduced specific gravity of soil biochar composite with increased biochar content could be the main reason for the drop in MDD value. Besides that, biochar's high porosity and SSA resulted in an increase in the OMC of soil after it was amended. These results were in line with previous works done by (GuhaRay et al., 2019; Sadasivam & Reddy, 2015).

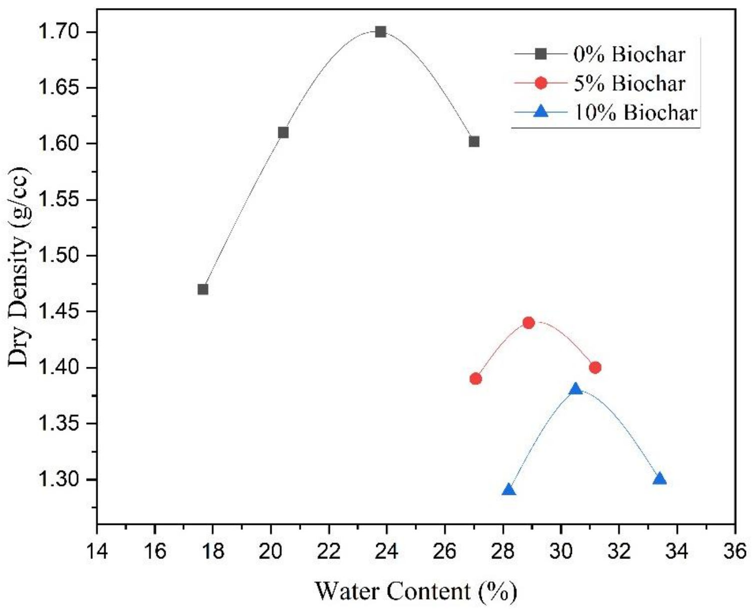

Figure 2*. MDD versus OMC for biochar soil composite*

3.3 Effect of biochar on the mechanical strength of expansive soil

Figure 3 depicts the effect of biochar content on the unconfined compressive strength of expansive soil. The UCS value of virgin soil was 250 kPa and it increased moderately with the addition of biochar up to 10% content. The UCS values for soil amendments containing 5% and 10% biochar were determined to be 499.57 kPa and 584.5 kPa, respectively. The improved interlocking between biochar and soil particles, as well as higher friction in the biochar-amended soil, could be the cause of the increased soil strength(Sudhakar & Varghese, 2018).

BSF (bio-char strength factor) is a novel index created by (Wani et al., 2022), according to which UCS in the soil is enhanced if BSF >1. The BSF values in this investigation were 1.99 and 2.33, confirming the claim that mesquite biochar application to soil resulted in increased strength.

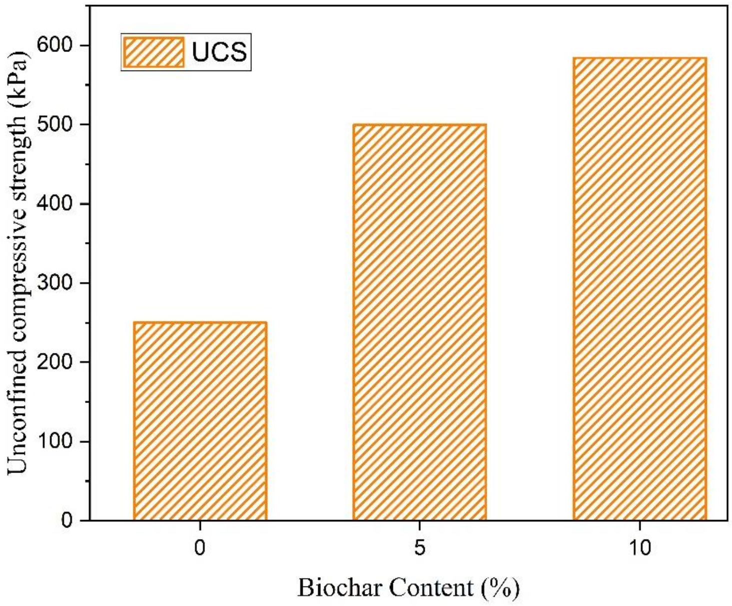

***Figure 3**. Variation of UCS value for soil biochar composite*

4 CONCLUSIONS

In this study, the influence of commercially purchased mesquite biochar produced by slow pyrolysis on the geotechnical properties of highly plastic clay was investigated. An increase in Atterberg limits and a decrease in plasticity index was observed with an increase in biochar content from 0% to 10%. However, a decrease in specific gravity, free swell index, as well as MDD values was obtained. The OMC value of both soil biochar composites, on the other hand, increased.

Mechanical testing of soil treated with mesquite biochar at 0%, 5%, and 10% was carried out to determine the unconfined compressive strength. The UCS value increased substantially as the biochar content in the soil increased. This was owing to improved biochar and soil particle interlocking as well as increased soil biochar composite friction.

These findings show that biochar's unique features have a significant impact on soil geotechnical behavior. The inclusion of such organic components can help to improve the CH-type soil's expansive nature and low strength. As a result, this research contributes to a better understanding of biochar's potential as a cost-effective and eco-friendly construction material.

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